

Supernova Model Discrimination with Hyper-Kamiokande

KING'S College LONDON

Jost Migenda (jost.migenda@kcl.ac.uk) for the Hyper-Kamiokande Proto-Collaboration PhD thesis (University of Sheffield) with full results at arXiv:2002.01649

Hyper-Kamiokande^[1]

- Next-generation water
 Cherenkov detector
- 258 (188) kton total (fiducial) mass, new high-efficiency PMTs
- Construction from 2020,
 data from 2027
- * Rich physics programme:
- * Nucleon decay
- * v oscillation & CP violation measurements
 - Solar & supernova v, indirect dark matter searches, ...
- Observe 54–90 k v from supernova at 10 kpc
 - $\bullet \quad 90\% \text{ via } \overline{v}_e + p \rightarrow n + e^+$
- * Energy threshold less than 5 MeV
- * 1° directional resolution to point astronomers
- → Can HK distinguish different SN models & identify which model best reproduces the explosion mechanism?

Supernova Toolchain

Supernova Models

- * Totani^[2]: classic 1D model
- * Nakazato^[3], Couch^[4]: 1D models
- * Tamborra^[5], Vartanyan^[6]: multi-D models

Event Generator: sntools^[7]

- * New, extensible & open source
- Precise cross sections for main channels in HK: inverse beta decay, ve⁻ scattering, charged-current interactions on ¹⁶O

Event Simulation and Reconstruction

- GEANT4-based detector simulation WCSim^[8]
- * Event vertex & energy reconstructed with BONSAI^[9] (same as Super-K)

Likelihood Function^[10]

• How likely is it that model M generates the observed events?

$$L_M = \ln \mathcal{L}_M = \sum_{\text{evt } i} \ln \frac{d^2 N_M(t_i, E_i)}{dt \ dE}$$

Results

- For each model & mass ordering, generated 1000 MC data sets during accretion phase (20–520 ms after core-bounce, largest differences between models)
- 300 events per data set, corresponds to SN at 56–96 kpc distance, i.e. anywhere in the Milky Way & its satellite galaxies
- * After simulation & reconstruction, find model with highest likelihood L_M for each data set

Identified as

 NMO/IMO
 Couch
 Nakazato
 Tamborra
 Totani
 Vartanyan

 Couch
 982/999
 2/1
 16/0
 0/0
 0/0

 Nakazato
 1/0
 999/1000
 0/0
 0/0
 0/0

 Tamborra
 16/0
 0/0
 980/974
 2/1
 2/25

 Totani
 0/0
 0/0
 0/0
 1000/1000
 0/0

 Vartanyan
 0/0
 0/0
 0/8
 0/0
 1000/992

How many data sets for a given model were identified as which model for normal/inverted mass ordering. (Assumes known MO.)

- Can identify true model with >97% accuracy
- If it observes the next galactic SN, HK can determine which simulation best reproduces the explosion mechanism realized in nature

If Hyper-Kamiokande observes the next galactic supernova, it can determine the explosion mechanism with high accuracy.